

# THE NEED FOR BIOLOGICAL EFFECTS MONITORING OF URBAN STREAMS IN WASHINGTON STATE

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## Executive Summary

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### I. Problem Definition

Pacific Northwest fish populations are susceptible to the toxicity of urban storm water. Salmon spawn in urban streams. Forage fish on which salmon depend are exposed to storm water contaminants along urbanized shorelines during spawning in winter. Copper is very bad for salmon and for the invertebrates on which they feed. Polycyclic aromatic hydrocarbons (PAHs) have very bad effects on fish eggs (embryos). Pesticides at low concentrations can have adverse effects to either fish or invertebrates. Storm water commonly contains metals, PAHs, and pesticides.

### II. The Need for Biological Monitoring of Storm Water Effects

Biological monitoring can guide and justify the commitment of public resources for urban runoff control. The public will better understand the biological consequences of water quality impairment or improvement than numbers generated by physical or chemical measurements. Chemical analysis is inadequate by itself. Many toxic pollutants cannot easily be detected by chemical analysis. Little toxicity information is available for many chemicals. Mixtures of chemicals can have unknown combined effects. Biological monitoring does not have these disadvantages and has demonstrated its usefulness in assessments related to storm water.

### III. The Need for Ambient Monitoring of Storm Water Effects

Ambient toxicity testing would better protect water quality by assessing the combined effects of all upstream sources. *In situ* testing reflects real environmental conditions. Toxicity testing can be done with important local species since we are not confined to only those tests approved for NPDES compliance monitoring. Far fewer samples and tests are needed than would be for monitoring numerous storm water outfalls. Monitoring of ambient water toxicity has a long history in Puget Sound and around the nation. The SeaTac Airport permit requires assessing storm water impacts by testing stream samples for toxicity to trout embryos and has withstood appeal before the Pollution Control Hearings Board. Ambient monitoring has different legal liabilities for permittees than discharge monitoring.

### IV. The Benefits of Integrated Receiving Water Monitoring Techniques

Monitoring would be best done using lab toxicity tests, *in situ* toxicity tests, and instream bioassessments in an integrated package. Instream bioassessments reflect real world conditions but cannot easily establish a cause and effect relationship. Laboratory tests can establish a cause and effect relationship, but that relationship may not reflect real world complexity. *In situ* toxicity testing falls in between field and laboratory techniques by exposing test organisms under environmental conditions while retaining some of the control of a lab test. These techniques together can provide information useful for controlling storm water.

### V. Urban Stream Monitoring Proposal

A small set of biological monitoring techniques can identify pollutants in urban streams at levels of concern and direct efforts to reduce these pollutants in storm water. The approach would be cost-effective and also protect urban bays. The proposal describes using benthic invertebrate assessments, toxicity testing of salmonid embryos and fry, and daphnid toxicity testing in an integrated system combining realistic environmental assessment with the ability to determine cause and effect relationships.

### VI. Regulatory Rationale

WAC 173-205-030(6) allows permits to require ambient toxicity testing in order to facilitate the determinations in WAC 173-201A-400(10)(b) which include demonstrating that a proposed mixing zone will not result in loss of habitat, interfere with beneficial uses, be a barrier to migration, or otherwise harm the ecosystem. A similar demonstration would be involved in complying with any narrative water quality standard.

## *I. Problem Definition*

Pacific Northwest fish populations are particularly susceptible to the toxicological effects of urban storm water runoff. Adult salmon return from the ocean to spawn in urban rivers and streams and their offspring must survive and develop within these urban areas. The forage fish on which adult salmon depend for food also have exposure to storm water contaminants along urbanized shorelines. Surf smelt and sand lance spawn in sediments in the intertidal zone along the increasingly urbanized shorelines of Puget Sound. Pacific herring spawn along the shores of bays near the mouths of urban streams which are dominated by storm water during the herring winter spawning season.

Copper is a ubiquitous storm water pollutant and may be the worst-case toxic metal for adverse effects to salmonids. The 96-hour  $LC_{50}$  for yearling coho salmon exposed to dissolved copper is in the range of 60 – 74  $\mu\text{g/L}$ . An EPA study found that dissolved copper at concentrations of 5  $\mu\text{g/L}$  or above impaired the migration of yearling coho downstream. [1] Other studies found a variety of adverse effects associated with copper. Juvenile chinook salmon exposed for 1 hour to dissolved copper concentrations at or above 50  $\mu\text{g/L}$  or for 4 hours to dissolved copper concentrations at or above 25  $\mu\text{g/L}$  lost a significant number of olfactory receptors resulting in a reduction in the ability to smell. [2] Fingerling rainbow trout exposed to dissolved copper concentrations of 10  $\mu\text{g/L}$  for 24 hours showed greatly increased mortalities from a common viral salmon pathogen (IHNV) compared to rainbow trout receiving a virus exposure but no copper and rainbow trout receiving a copper exposure but no virus. [3] Steelhead salmon embryos, alevins, and fry intermittently exposed to copper for 4.5 hours each day for 78 days exhibited greater impairment than other steelhead salmon of the same age continuously exposed to the same concentrations indicating that water quality criteria based on continuous exposures may be inadequately protective for intermittent exposures to contaminants in runoff from rain events. [4]

Polycyclic aromatic hydrocarbons (PAHs) are another class of compounds that are ubiquitous in urban runoff. PAHs are persistent, bioaccumulative, and often toxic. The most serious consequences from PAH exposure occur in the earliest life stages of fish. Surf smelt hatched from eggs exposed to Eagle Harbor and Elliott Bay sediments containing PAH levels as low as 10 mg/kg along with other contaminants had increased mortalities, malformations, and decreased growth. [5] Studies have shown reduced survival and increased developmental problems in pink salmon hatched from eggs exposed in a laboratory to PAH concentrations in water at 16.4 ppb and perhaps as low as 1.0 ppb. [6, 7] Dissolved and particulate PAHs at levels perhaps as low as 0.7 ppb produced mortalities, malformations, genetic damage, decreased size, and impaired swimming in Pacific herring hatched from eggs exposed for 16 days in a laboratory. [8] Some PAHs become much more toxic after exposure to sunlight. [9, 10]

Because urban runoff is freshwater and usually warmer than marine waters in regional urban bays, it will float on top of the saltwater in the bay and deliver contaminants directly to the sea surface microlayer. Sand sole eggs incubated in surface water samples taken from Elliott Bay and Commencement Bay in February and March had reduced hatching success and increased chromosomal aberrations relative to samples from Sequim Bay and Central Puget Sound. Sand sole eggs incubated at the same time in floating containers out in Elliott Bay and Commencement Bay had half the hatching success as in Sequim Bay and were used to verify the results of the laboratory testing. A statistical evaluation of the chemicals found in surface water samples showed that toxicity was likely due to a combined effect of the PAHs, pesticides, PCBs, and metals in the surface water layer of the urban bays. [11, 12]

Organophosphorus and carbamate pesticides are toxic to fish and act by inhibiting a compound which regulates nerve impulses (acetylcholinesterase). These pesticides are widespread in urban and agricultural runoff. Diazinon, an organophosphorus pesticide, has been found to inhibit antipredator behavior in juvenile chinook salmon exposed to 1  $\mu\text{g/L}$  for 2 hours and to inhibit homing behavior in maturing chinook salmon exposed to 10  $\mu\text{g/L}$  for 24 hours. [13] Based on another study showing that diazinon blocks the ability of male Atlantic salmon to smell roe immediately after deposition by a female resulting

in interference with milt release, [14] the scientists suggest similar olfactory impairment is involved in reducing chinook salmon antipredator and homing behavior in their study.

## *II. The Need for Biological Monitoring of Storm Water Effects*

The beneficial uses for the nation's waters in the Clean Water Act are biological in nature. Biological monitoring will be important for guiding and justifying the commitment of public resources for urban runoff control. The public will better understand explanations based upon the biological consequences of water quality impairment or improvement than on numbers generated by physical or chemical assessments. Success measures that show improvements for our aquatic and marine species are a prerequisite for a sustained effort in managing storm water.

Chemical analysis of storm water or receiving water samples is inadequate by itself for evaluating environmental impacts. Many toxic pollutants cannot be detected by commonly available chemical analyses. Many of the chemicals that can be detected have little toxicity information available on them. Many of the chemicals with known toxicity have unknown additive or synergistic effects when present in complex mixtures. A study mentioned above showed that intermittent exposures to copper were worse for steelhead embryos, alevins, and fry than continuous exposures at the same concentrations. [4] A study of runoff toxicity in the Vancouver BC area looked into the contribution to toxicity of four metals at concentrations found in storm water and found that lead enhances the toxicity of copper and zinc and that iron reduces the toxicity of copper, zinc, and lead. [15]

The following are some examples of the kinds of benefits from biological monitoring techniques:

- Samples collected from urban streams in Sacramento and Stockton, California during the rainy season were tested for toxicity to daphnids. Thirty-six of 47 samples (76.6%) produced total mortality within 72 hours. Toxicity identification evaluations confirmed that toxicity was primarily due to diazinon and chlorpyrifos use in urban areas. Pesticide concentrations were lower in a commercial and industrial area compared with a residential area. [16]
- Toxicity tests were used to evaluate the effectiveness of an urban runoff treatment marsh in Fremont, California. The study produced a recommendation to increase storm water detention in order to facilitate additional toxicant removal. The same toxicity tests were used afterwards to document improvements in performance after floating baffles were installed to increase detention time and discourage discharge of water from the more toxic surface layer. [17]
- An assessment of fish populations in the Willamette River showed that point source discharges contributed much less to the gradual downstream decline in water quality and fish species diversity than did natural causes and nonpoint source discharges. The study also found that fish populations had improved in some locations in recent years and suggested that impoundment of winter runoff to compensate for the loss of natural storm water runoff storage systems was responsible. [18]
- A study of fish populations in Kelsey Creek in Bellevue, Washington found that both salmon and other native fish species were displaced by cutthroat trout within the urbanized watershed. A simultaneous study of the nearby but rural Bear Creek found a more natural balance of fish species which included many more coho and chinook salmon than in Kelsey Creek. Urbanization seems to favor cutthroat trout over both salmon and non-salmonid fish such as sculpins. [19]
- A study quantified the changes in fish populations from 1958 to 1990 in Tuckahoe Creek, a Virginia stream subjected to gradual urbanization of its watershed. This study found a similar change in fish population structure as that discussed above for Kelsey Creek. Bluegills and common shiners had become the dominant fish species rather than a once greater variety of fish. Reductions in benthic invertebrates were thought to be a major cause of this shift in species structure. [20]
- In order to develop information to use in establishing guidelines for nearshore development in British Columbia, the Canada Department of Fisheries and Oceans recently did an assessment of the fish species which use Burrard Inlet. Burrard Inlet is within the urban area of Vancouver and is bordered by residential development. The study found that habitat and the fish species which depend on it

appeared to be healthy in Burrard Inlet at that time. By quantifying which fish species use Burrard Inlet at different seasons of the year, the study produced a baseline for comparing future monitoring of fish populations and preventing significant habitat destruction. Other shoreline habitats in the Vancouver area were already degraded by industrial and commercial development which occurred before their fish populations had been assessed. [21]

### ***III. The Need for Ambient Monitoring of Storm Water Effects***

Routine ambient toxicity testing would identify toxicity hotspots allowing resources to be focused on higher priority problems. A study in Chesapeake Bay demonstrated that ambient toxicity tests can find exceedances of water quality criteria and detect unknown toxicants. [22] Another Chesapeake Bay study found ambient toxicity test results to correlate well with fish community diversity. [23].

The advantages of ambient toxicity testing are:

- Toxicity tests are broad spectrum and will detect any toxicant or toxicant combination. Chemical analysis is only efficient when all of the potential toxicants are known and the list is small in number. When there is a large number of potential toxicants or the possibility of unknown toxicants, toxicity testing is the best method for assessing water quality at least initially.
- A far smaller number of samples and tests are needed for assessing ambient water quality than would be for monitoring the numerous storm water outfalls for individual chemicals and toxicity. The cost will be much lower for sampling, testing, and data management.
- Ambient toxicity tests assess environmental impacts under real world conditions. There is no need to worry whether the analytical method is over-estimating impacts by including nonbioavailable fractions in the evaluation. Tests conducted on ambient samples or in the stream itself will detect the toxicity from all upstream sources: point sources (industries and POTWs), nonpoint sources (storm water and groundwater), and natural (toxic phytoplankton).
- Toxicity tests can be chosen to fit specific circumstances. Testing can be done with important local species that were not necessarily used in deriving the chemical-specific water quality criteria. The variety of toxicity tests available for ambient testing is quite large since we are not confined to only those tests approved for NPDES compliance monitoring.
- An ambient toxicity monitoring program would generate information relevant to attainment of beneficial uses and other water quality standards and would eventually provide justification for increasing or reducing permit requirements.
- Getting samples of storm water discharges that accurately represent the environment is very difficult. Storm water toxicity varies widely as pollutant loading rises and falls and as the proportion of toxicants in the dissolved versus suspended state changes rapidly. A study measured storm water toxicity to daphnids in samples taken every 20 minutes during a 4-hour rain event in Vancouver BC and found a toxicity peak in the first flush, another worse peak about 2 hours into the rain event, and then the worst toxicity a little past 3 hours into the storm. [4]
- Monitoring of ambient water toxicity has a long history in Puget Sound [24-27] and has been used around the nation to assess the impacts of nonpoint source discharges [28-30]. The NPDES permit for SeaTac Airport contains requirements to test stream samples for toxicity to rainbow trout embryos in order to assess the impact of storm water runoff. These requirements withstood appeal before the state Pollution Control Hearings Board.

### ***IV. The Benefits of Integrated Receiving Water Monitoring Techniques***

Meaningful storm water monitoring would be best done using lab toxicity tests, *in situ* toxicity tests, and instream bioassessments in an integrated package [31-34]. The same test species should be used for both *in situ* and laboratory testing so that an integrated approach can work. Instream bioassessments reflect real world conditions but cannot easily establish a cause and effect relationship because of both known and unknown factors that interact in complex ways. Laboratory tests can establish a cause and effect

relationship by keeping all factors constant except the one factor of interest, but that relationship may not remain intact in the complex real world. *In situ* toxicity testing falls in between field and laboratory techniques by exposing test organisms under environmental conditions while retaining some of the control of a lab test.

Laboratory tests provide the controlled conditions needed to separate effects due to toxicity from other stressors. Toxicity identification evaluations (TIEs) for identifying unknown toxicants can only be performed in a lab. Quality assurance procedures such as reference toxicant testing are laboratory-based. Laboratory tests can be performed on a series of dilutions so that the concentration-response relationship can be evaluated to detect anomalous test results or to estimate how much additional reduction in storm water pollutants is necessary. Extreme weather or flow conditions can prevent successful *in situ* monitoring but have little influence on the availability of laboratory toxicity tests. Lab tests should be performed on ambient samples, and storm water discharge samples tested only when necessary to find sources of ambient toxicity.

*In situ* testing is done by exposing test organisms in a test chamber that is placed in the stream under realistic exposure conditions. *In situ* testing avoids the need to choose between grab versus composite sampling, time-weighted versus flow-weighted composites, first flush sampling versus peak flow, etc. Storm water toxicity often occurs in pulses [4, 35] and laboratory tests performed on samples collected during or between pulses will either over-estimate or under-estimate toxicity. Water hardness, temperature, pH, dissolved solids, suspended solids, dissolved oxygen, and exposure to sunlight can all affect toxicity and only *in situ* testing can reflect actual environmental conditions. *In situ* testing locations should coincide with instream bioassessment locations so that results can be used in interpreting bioassessment results for that location.

Environment Canada has developed and uses laboratory tests and *in situ* tests on early lifestages of rainbow trout [36-37]. The permit for SeaTac Airport requires sampling of adjacent streams for lab testing using the trout embryo test. The *in situ* trout procedure has been used in Canada to assess the effects of mining discharges. [38] Rainbow trout are in the same genus as our endangered salmon and are available year round. The same technique can be done using other salmon such as coho when they are available. Salmonid embryos are highly sensitive when exposed to a variety of environmental contaminants [39-43]. In addition, many of the studies discussed above raise serious concerns about storm water pollutant effects on the embryos of other important fishes in Washington State. Studies have shown that rainbow trout and Atlantic salmon fry are the most sensitive lifestage to nonylphenol, a common environmental contaminant that is sometimes found in storm water. [44-45]

The *in situ* procedure involves an exposure of trout beginning at the eyed-embryo stage. The laboratory version of the test might be more sensitive because embryo exposure begins soon after fertilization. Test endpoints include survival, normally developed larvae, and larval growth. In addition to the test endpoints, the tissue concentrations of anthropogenic chemicals can be measured at test termination to determine whether the fish were exposed to bioconcentratable pollutants. This may also provide insight into causes of reductions in normal development or growth. The *in situ* test can be continued into or begun with the fry lifestage to account for toxicants affecting fry more than embryos. Every lifestage used in the *in situ* salmonid testing has a laboratory version which can verify and identify toxicants.

Bioassessments are the most direct measure available of ecosystem health. Benthic invertebrates are by far the easiest organisms to survey for impacts because they are less mobile than organisms which swim or drift in the water column. These benthic organisms sustain a nearly constant exposure by remaining nearly stationary and are easy to collect and quantify. Benthic invertebrates are a key food source for fish in streams. For these reasons, monitoring of benthic invertebrate communities is widely used for evaluations of stream health by use of metrics such as the Benthic Index of Biotic Integrity (B-IBI). The B-IBI is an effective and generally reproducible tool for evaluations of benthic invertebrates and the quality of the environment that supports them. Bioassessments also detect adverse effects that are not related to toxicity

such as siltation, scouring by floods, diseases, or natural population cycles. Any toxicity causing adverse effects to benthic invertebrate populations might come from water and/or sediments.

A method for benthic invertebrate monitoring in which rocks are put in cages, placed on or within bottom sediments, and evaluated later for colonization by benthic invertebrates has been used in Maine and elsewhere. The *in situ* colonization test can produce similar results to those obtained by traditional B-IBI measurements at a lower cost. This method allows control over substrate type and size in order to avoid sediment quality differences between stream stations which reduce the ability to separate toxic effects from substrate effects in B-IBI results. It also allows more control over siting in order to determine sources of toxicity, more frequent measurements at many locations than possible by sampling from benthic communities, and the ability to assess locations inaccessible for traditional B-IBI measurements.

Daphnid acute tests are widely available, relatively inexpensive, and good surrogates for benthic invertebrates. Daphnids have proven to be reliable in both laboratory testing and for *in situ* monitoring of storm water. Daphnids are known to be among the most sensitive of test organisms to metals and pesticides [15, 46-47] and will provide protection for salmonids against the effects of copper and pesticides discussed above. A study in California found that diazinon and chlorpyrifos are significantly more persistent in seawater and recommended that these pesticides be reduced in freshwater streams before entering saltwater. [47] EPA has developed toxicity identification procedures using daphnids which have successfully identified unknown toxicants in storm water.

#### ***V. Urban Stream Monitoring Proposal***

A small set of biological monitoring techniques can detect and identify pollutants at levels of concern for environmental harm to urban streams and help direct efforts to reduce these pollutants in storm water. The approach proposed here might be the most cost-effective available for this purpose. Once thoroughly implemented within an area, it would also protect urban bays and their fish populations from ongoing contamination from storm water conveyed by urban streams.

1. Monitor benthic invertebrate communities at standardized locations by use of the Benthic Index of Biotic Integrity (B-IBI).
2. Use the *in situ* benthic invertebrate colonization method to increase measurement frequency and resolve uncertainty as to the source of impairment found by the B-IBI.
3. Use daphnids or amphipods in laboratory or *in situ* testing to verify and then identify toxicants which may be adversely affecting invertebrate populations as determined by the B-IBI or *in situ* colonization methods. If toxicity is not verified by lab or *in situ* testing, assume toxicity is not the cause of the adverse effects.
4. Conduct *in situ* testing using rainbow trout embryos and fry at the same locations as the B-IBI measurements. When toxicity is detected, include additional upstream locations to find sources. Analyze tissue concentrations if necessary.
5. Use the laboratory versions of the trout tests to verify and identify toxicants.
6. Measure temperature, pH, dissolved oxygen, total suspended solids, hardness, alkalinity, conductivity, and stream flow at the same times and locations to provide inexpensive supplemental information.

## VI. Regulatory Rationale

Whether in anticipation of narrative standards or eventual numeric limits for storm water pollutants, biological monitoring of urban streams conducted pursuant to WAC 173-205-030(6) would be a prudent step to take now. Environmental problems would be found sooner and fixed. Progress in protecting urban streams could be documented using biological data of obvious relevance. Because streams convey pollutants to urban bays, the bays would receive some protection as well. Biological monitoring in the receiving streams would involve far fewer sampling points and analyses than traditional discharge monitoring. The information generated would support the regulatory determinations discussed below.

WAC 173-205-030(6) says:

The department may conduct or require permittees to conduct toxicity tests on ambient water or may use or require permittees to use ambient water as dilution water in order to facilitate the determination of compliance with WAC 173-201A-100 (now WAC 173-201A-400).

WAC 173-201A-400(10)(b) sets conditions for when exceedances of the mixing zone size limits and overlap criteria are allowable. These conditions include demonstrating to the department's satisfaction that the proposed mixing zone will not result in the loss of habitat, interfere with beneficial uses, be a barrier to migration, or otherwise harm the ecosystem. Given the small size of many urban streams and the large number of storm water outfalls discharging to them, it will be difficult to implement numeric water quality criteria without the ability to allow exceedances of the mixing zone size and overlap criteria where justified. 40 CFR 122.44(d)(1)(ii) requires the permitting authority to account, where appropriate, for dilution of the effluent in the receiving water in assigning either a chemical-specific or a WET limit. In addition, the conditions in WAC 173-201A-400(10)(b) are much the same as the considerations which would apply in determining compliance with a narrative standard for maintaining water quality. The integrated biological monitoring in this proposal could be used to determine compliance with a narrative water quality standard, establish where exceedances of mixing zone size or overlap criteria are justified, evaluate progress in managing urban storm water, and provide for a cost-effective and more direct measure of watershed health. In doing so, it would supplement the assessments related to other storm water concerns such as flow and pollutant loading in achieving a comprehensive management system.

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